After the 2010 rains: changes in reporting rates of birds in remnant woodland vegetation in the central wheatbelt of New South Wales, Australia, from drought to post-drought

Murray V. Ellis[1] and Jennifer E. Taylor[2]

[1] Population Analysis and Modelling Unit, NSW Office of Environment and Heritage, PO Box 1967, Hurstville BC NSW 1481, Australia

[2] School of Arts and Sciences, Australian Catholic University, PO Box 968, North Sydney, NSW 2059 Australia.

ABSTRACT

Loss and fragmentation of the native vegetation of the Central Western Plains of New South Wales was followed by declines of woodland-dependent species. Drought is likely to have further suppressed many animal populations. Here we report on changes in woodland bird reporting rates between surveys in 2005-2009 (drought declared period) and surveys in 2010-2013 following the drought-breaking rains of 2010. By 2013 the number of species detected per survey had just recovered to the level of surveys in 2005/6. The 2013 species composition of the region was similar to that recorded in the 2005-2009 drought surveys, with half of the small insectivorous and nectarivorous woodland birds remaining rare and restricted. Woodland remnants in the landscape continued to be dominated by the same, usually large, species of birds, but reporting rates of 13 of the 15 most common species declined. Conversely, several smaller, foliage gleaning passerines had higher reporting rates post-drought, with Striated Pardalote and Western Gerygone becoming two of the most frequently recorded species. Taxonomic and life history attributes usually did not predict population changes for species post-drought, with the only feeding guild showing a consistent trend being the mistletoe specialists, with only two species. Even after the drought-breaking rains of 2010, there appears to be a reduced vigour in these woodland landscapes.

Key words: avifauna, box woodland, drought recovery, fragmentation, temperate eucalypt woodland

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Introduction

Woodlands once covered a million square kilometres of Australia and dominated the inland of south-eastern and south-western Australia, but extensive grazing and clearing for cereal cropping has greatly reduced and modified them (Yates and Hobbs 1997; Cox *et al.* 2001; Lunt *et al.* 2006; Bedward *et al.* 2007). Many bird species and communities are now restricted to remnant vegetation (Ford 2011) and there is evidence of population decline of many woodland bird species (Barrett *et al.* 1994; Barrett and Silcocks 2002; Barrett *et al.* 2007; Mac Nally *et al.* 2009). The central wheatbelt of New South Wales (NSW) is one such area that has undergone major losses of biodiversity (Ayers *et al.* 1996) and for which there is evidence of declines of some bird species (Ellis and Taylor 2013). At the time of writing, 98 species and communities for the Bogan-Macquarie subregion of the Central West Catchment Management Authority Region (the focal area of this study) were listed under the NSW *Threatened Species Conservation (TSC) Act 1995* (http://www.environment.nsw.gov.au/threatenedSpeciesApp/cmaSearchResults.aspx?SubCmaId=843).

Rainfall in the inland woodlands is variable from year to year, with prolonged periods of low rainfall resulting in loss of ground cover and canopy foliage, and sometimes tree death (Fensham and Holman 1999; Jurskis 2005; Brouwers *et al.* 2013). These stresses reduce the availability of nectar (Watson 2011), seeds (Davies 1976), and arthropods (Bell 1985; Taylor 2008; Stone *et al.* 2010), which provide key food sources for a range of woodland birds (Barker and Vestjens 1989, 1990). Reduced abundance of these resources affects the abundances of woodland birds in Australia (Recher *et al.* 1996) and has negative impacts on birds in semi-arid North America (Albright 2010). Indeed, the meta-analysis by Mac Nally *et al.* (2009) of population trends in birds from Victorian woodlands indicates a widespread collapse due to loss of resources caused by fragmentation and degradation, and exacerbated by climate change. Conversely, rainfall promotes breeding among a variety of Australian birds (e.g., Zann *et al* 1995; Burbidge and Fuller 2007). Thus, it is expected that populations of woodland bird species would decline during droughts but may increase during periods of higher rainfall.

From 2001-2009 much of semi-arid, south-eastern Australia was drought declared. In 2010, the drought broke. If drought is a major factor limiting birds then high rainfall periods would be expected to result in increases in species richness and abundance as food resources increase. However, the high degree of fragmentation of the woodlands of south-eastern Australia is also cited

as an important influence of population dynamics of birds (Ford 2011). Longitudinal studies are important to understanding the capacity of these highly-fragmented lands to recover after natural and human-induced disturbances, and for separating population changes due to climatic variation from fluctuation due to other sources (Smith 1982). Long-term studies also provide baseline data of the status of bird populations for comparison over time and can guide effective conservation in agricultural landscapes (Lindenmayer and Cunningham 2011).

The broad aim of our larger study was to document changes to the avifauna in woodland in the Macquarie-Bogan sub-region of central-western NSW over time and to investigate relationships with landscape and climatic conditions. In this paper we compare reporting rates for landbirds following the drought breaking rains of 2010 to those during the drought declared period 2005-2009. We used this comparison to investigate if increased resource availability produced similar population responses across all species.

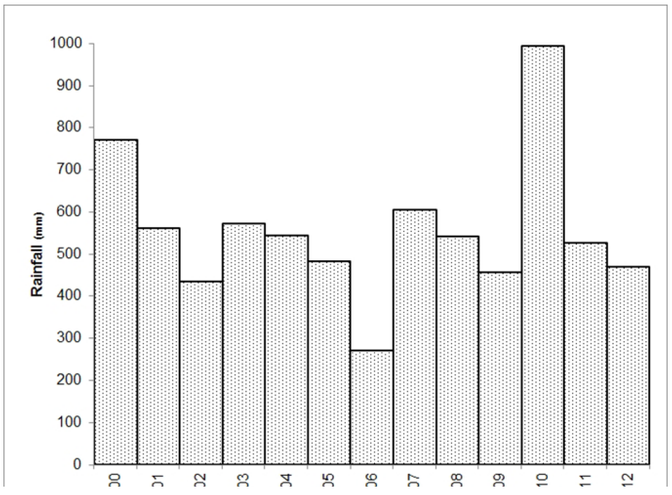

Figure 1. Annual rainfall totals at Narromine in the north west of the study area (Source: Bureau of Meteorology station 51037).

Figure 2. Floodwater in December 2010 flowing through a site adjacent to the Macquarie River channel which is 50 m to the left of the picture. Debris caught in the trees indicates that the water was over 3m deep on the site at the flood peak (M. Ellis).

Figure 3. A sward of Kangaroo Grass ***Themeda australis*** setting seed at the edge of one of the plains woodland sites, March 2011 (J. Taylor).

Methods

Study area

Our study was conducted in a 100 km X 100 km area centred on 148° 00' E, 32° 30' S between Narromine and Tullamore in the central wheatbelt on the western plains of New South Wales below an altitude of 300 m. Mapping of the sites is provided in Ellis and Taylor (2013). The vegetation of the area was originally *Eucalyptus*, *Callitris,* and *Acacia* woodlands. However, by the mid 1980s < 37% of the native vegetation remained and there were further losses amounting to 10% of woody vegetation in the subsequent 15 years (Metcalfe *et al.* 2003). Further details of the vegetation and history of clearing of the study area are in Metcalfe *et al.* (2003), Lunt *et al.* (2006), Bedward *et al.* (2007), and Ellis and Taylor (2013). A map of the relictual woodlands of the study area is presented in Ellis and Taylor (2013).

The climate of the study area is temperate and semi-arid with annual rainfall of approximately 500 mm (Metcalfe *et al.* 2003) and high inter-annual variation (Ellis and Taylor 2013). The annual recorded rainfall for Narromine over 121 years ranged from 217 to 1386 mm with a mean of 527mm (Source: Bureau of Meteorology station 51037). Drought was declared across the study area and neighbouring catchments for much of the period 2002 – 2009 with a series of low rainfall and high evaporation (over 2000 mm per annum in the north west of the study area (Ellis and Taylor 2013) years. Following heavy rains in 2010 (Fig. 1) and smaller falls in 2011 and 2012, many riparian sites flooded (Fig. 2) and grass and foliage growth was often abundant (Fig. 3).

Bird sampling

Survey sites were established at 142 locations over three seasons as described in Ellis and Taylor (2013). Sites were located across the range of tree densities in the Plains and Riparian vegetation types (Metcalfe *et al.* 2003) in the study area. Sites were in travelling stock routes and reserves, road

verges, and reserves. Many sites were subjected to irregular grazing by domestic stock during the study. Further details of site selection are in Ellis and Taylor (2013).

Repeated, 10 minute active searches (Ellis and Taylor 2013) of the one-hectare (100 m x 100 m) sites occurred during four spring/summer periods from 22 November 2005 to 8 April 2009 during the drought with a total of 11 to 24 surveys per site (mean 5.10 per period) depending on when the site was first established (Ellis and Taylor 2013). Post-drought surveys were conducted during three spring/summer periods from 10 November 2010 to 14 December 2012 with 10 to 19 surveys per site (mean 4.97 per period) depending on site accessibility (e.g., flooding and road closures). Birds were recorded when detected by either sighting or sound on the site ("on-site") or in the surrounding landscape ("off-site"). We recorded whether they were flying past or not, how far from the site they were if off-site, and the number of individuals detected, as described in Ellis and Taylor (2013). Incidental records while travelling between sites are not included in analyses. Because all surveys were done during daylight in woodland remnants, and we did not systematically survey wetlands, this method does not provide reliable data for species of waterbirds or nocturnal species. All except the two rounds of drought surveys mentioned in Ellis and Taylor (2013) were conducted by the authors.

Reporting rates were calculated as the number of surveys in which each species was recorded, both on- or off-site, divided by the number of surveys during the relevant sampling period and expressed as a percentage.

Results

One hundred and ninety bird species were recorded during our studies; 154 were landbirds (Table 1). During the drought surveys 145 landbird species were recorded and post-drought 130. Ninety-three (60%) landbird species were recorded in less than 1 % of surveys during both the drought and post-drought periods and are considered rare in these remnants. Twenty-one species had reporting rates greater than 10% in either sampling period, with 16 species having reporting rates greater than 10% in both sampling periods (Table 1). For species with a reporting rate greater than 1%, if the ratio of the post-drought to drought reporting rates was greater than 1.2 the species was described as "increaser" (> 20% increase), and if less than 0.8 as "decreaser" (> 20% decrease).

Changes in reporting rate

Seventy-nine species were reported more frequently post-drought ("Δ rates" positive in Table 1), while 75 were more reported during the drought period ("Δ rates" negative in Table 1). The 15 most frequently reported species in the drought period surveys were, in descending order, Galah, Noisy Miner, Australian Magpie, Crested Pigeon, Magpie-lark, Apostlebird, Australian Raven, Eastern Rosella, Grey-crowned Babbler, Pied Butcherbird, Blue Bonnet, Cockatiel, Red-rumped Parrot, Grey Butcherbird, and White-winged Chough with reporting rates from 70 to 15%. During the post-drought surveys Striated Pardalote, Western Gerygone, and Willy Wagtail joined the top decile, displacing Australian Raven, Cockatiel and Red-rumped Parrot, with reporting rates for the top decile ranging from 59 to 14% during that period.

Barrett *et al.* (2007) defined declining and increasing species as those with at least 20% change in reporting rates between the two sets of Atlas surveys (Blakers *et al.* 1984 and Barrett *et al.* 2003). Using the same definition for species with reporting rates >1%, 35% of species increased, 25% declined and 40% showed no change in reporting rate post-drought in our study (percentages were similar if all species were considered or for a threshold reporting rate of 3%).

Nine of the species recorded in more than 1% of surveys post-drought more than doubled in reporting rate since the drought (ratio > 2, Table 1). Among these, the greatest increases post-drought were for Stubble Quail, Double-barred Finch, and Superb Fairy-wren, all showing more than a five-fold increase in reporting rates post-drought. However, reporting rates for all remained below 6% post-drought. Conversely, five of the species recorded in more than 1% of surveys during the drought had a decreased reporting rate post-drought that was less than half that during the drought period: Jacky Winter, Australian Raven, Cockatiel, Superb Parrot, and Fairy Martin (ratio <0.5, Table 1).

Twenty four species recorded during the drought were not seen post-drought, but all had drought period reporting rates below 0.4% and half of these species are at the edge of their distributional range in our study area (Blakers *et al.* 1984; Table 1). Of the nine species recorded post-drought, but not during the drought, all had reporting rates below 0.2% and five species were at the edge of their distributional range in our study area (Table 1). In total, there were 40 species of landbird recorded during the drought (35 spp.) or post-drought (28 spp.) that were at the edge of their distributional range based on Blakers *et al.* (1984) (Table 1). Eight of these species had post-drought reporting rates above 1%: Singing Honeyeater, Little Crow, Chestnut-rumped Thornbill, Superb Parrot, Little Corella, Mallee Ringneck, Superb Fairy-wren, and Yellow-throated Miner. The two parrots had decreased reporting rates post-drought, there was no change in reporting rate of the Yellow-throated Miner, and the other five species had reporting rates that increased between 1.5 to 5.4 times that during the drought (Table 1).

The median number of species recorded per survey was six or seven across all years, while the upper quartile declined across the drought periods, but increased across the post-drought periods (Table 2). The mean number of species recorded per survey declined during the drought period and was at its lowest at the beginning of the post-drought survey period, after which it increased (Fig. 5).

Threatened species

Seventeen of the land bird species detected are listed under the NSW *Threatened Species Conservation Act 1995* (Table 1). The only threatened species that was commonly recorded was the Grey-crowned Babbler and its reporting rate increased slightly post-drought to over 28%. Three threatened species had reporting rates from

Table 1. Reporting rates for landbird species at sites during the drought and post-drought survey periods, the change in the rate, ratio of post-drought to drought rate and their ranking during the two periods (highest reporting rate ranked 1 in each period). Species marked with * are listed under the NSW ***Threatened Species Conservation Act 1995***. Species marked † were at the edge of their distributional range in our study area based on Blakers ***et al.*** (1984). Species are listed in taxonomic order.

Common name	Drought rate (%)	Post-drought rate (%)	Δ Rates	Ratio	Drought rank	Post-drought rank
Emu	0.24	0.14	-0.001	0.59	80	93
Stubble Quail	0.14	2.27	0.0213	16.42	94	49
Brown Quail †	0.03	0.28	0.0025	8.21	123	79
Painted Button-quail	0.03	0	-0.0003	0	123	131
Little Button-quail	0.03	0.24	0.002	6.84	123	84
Peaceful Dove	6.14	6.23	0.0009	1.01	25	29
Diamond Dove	0.38	0.05	-0.0033	0.12	74	109
Bar-shouldered Dove	0.1	0.28	0.0018	2.74	100	79
Common Bronzewing	4	4.11	0.001	1.03	32	37
Crested Pigeon	39.67	28.08	-0.1159	0.71	4	7
Rock Dove	0.03	0	-0.0003	0	123	131
Spotted Harrier *	0.34	0.24	-0.0011	0.68	76	84
Swamp Harrier	0.1	0.05	-0.0006	0.46	100	109
Brown Goshawk	0.21	0.28	0.0008	1.37	86	79
Wedge-tailed Eagle	1.24	0.66	-0.0058	0.53	52	65
Little Eagle *	0.28	0.14	-0.0013	0.51	78	93
Whistling Kite	0.55	0.14	-0.0041	0.26	68	93
Black Kite	0.52	0.28	-0.0023	0.55	70	79
Square-tailed Kite *	0.03	0	-0.0003	0	123	131
Black-shouldered Kite	0.55	0.99	0.0044	1.8	68	59
Australian Hobby	0.66	0.57	-0.0009	0.86	66	68
Grey Falcon * †	0.03	0.05	0.0001	1.37	123	109
Peregrine Falcon	0.07	0.09	0.0003	1.37	108	102
Black Falcon	0	0.14	0.0014		146	93
Brown Falcon	0.72	0.52	-0.0021	0.72	65	71
Nankeen Kestrel	1.79	1.09	-0.0071	0.61	48	57
Glossy Black-Cockatoo * †	0.17	0.24	0.0006	1.37	89	84
Sulphur-crested Cockatoo	5.55	6.51	0.0096	1.17	29	27
Major Mitchell's Cockatoo * †	0.24	0.09	-0.0015	0.39	80	102
Little Corella †	1.83	3.35	0.0152	1.83	47	39
Galah	70.58	55.92	-0.1465	0.79	1	2
Cockatiel	21.32	8.45	-0.1287	0.4	11	25
Superb Parrot * †	6.07	2.97	-0.031	0.49	26	43
Red-winged Parrot †	0.03	0.05	0.0001	1.37	123	109
Australian King-Parrot †	0.07	0	-0.0007	0	108	131
Eastern Rosella	26.7	25.58	-0.0112	0.96	8	8
Mallee Ringneck †	6.21	3.54	-0.0267	0.57	24	38
Red-rumped Parrot	19.83	12.27	-0.0756	0.62	13	16
Mulga Parrot †	0.07	0	-0.0007	0	108	131
Blue Bonnet	21.32	13.92	-0.074	0.65	11	14
Turquoise Parrot * †	0.03	0	-0.0003	0	123	131

Common name	Drought rate (%)	Post-drought rate (%)	Δ Rates	Ratio	Drought rank	Post-drought rank
Budgerigar †	0.28	0.09	-0.0018	0.34	78	102
Pallid Cuckoo	0	0.19	0.0019		146	88
Fan-tailed Cuckoo	0.17	0.33	0.0016	1.92	89	77
Brush Cuckoo †	0	0.05	0.0005		146	109
Black-eared Cuckoo	0.14	0.09	-0.0004	0.68	94	102
Horsfield's Bronze-Cuckoo	0.1	0.24	0.0013	2.28	100	84
Shining Bronze-Cuckoo	0.03	0.05	0.0001	1.37	123	109
Southern Boobook	0.07	0.52	0.0045	7.52	108	71
Barking Owl *	0.03	0.05	0.0001	1.37	123	109
Tawny Frogmouth	0.03	0.09	0.0006	2.74	123	102
Australian Owlet-nightjar	0.03	0	-0.0003	0	123	131
Spotted Nightjar †	0.03	0	-0.0003	0	123	131
Dollarbird	1.35	1.56	0.0021	1.16	51	53
Laughing Kookaburra	8.93	9.91	0.0098	1.11	20	21
Red-backed Kingfisher	0.07	0.09	0.0003	1.37	108	102
Sacred Kingfisher	3.83	6.28	0.0245	1.64	33	28
Rainbow Bee-eater	1.72	1.7	-0.0003	0.99	49	52
White-throated Needletail	0.1	0	-0.001	0	100	131
Fork-tailed Swift	0.03	0	-0.0003	0	123	131
Brown Treecreeper *	4.93	3.07	-0.0187	0.62	30	42
White-throated Treecreeper †	0.03	0.19	0.0015	5.47	123	88
White-browed Treecreeper †	0.38	0	-0.0038	0	74	131
Superb Fairy-wren †	1.1	5.95	0.0484	5.39	56	32
Splendid Fairy-wren †	0.1	0.14	0.0004	1.37	100	93
White-winged Fairy-wren †	0.24	0.47	0.0023	1.95	80	74
Variegated Fairy-wren	0.17	0.57	0.0039	3.28	89	68
Spotted Pardalote	0.14	0.33	0.0019	2.39	94	77
Striated Pardalote	10.59	19.21	0.0862	1.81	19	10
Speckled Warbler *	0.21	0.47	0.0026	2.28	86	74
Western Gerygone	7.21	15.05	0.0784	2.09	22	12
Striated Thornbill †	0.17	0.14	-0.0003	0.82	89	93
Yellow Thornbill	2.07	3.35	0.0128	1.62	46	39
Brown Thornbill †	1.17	0.8	-0.0037	0.68	53	63
Inland Thornbill †	0.21	0.05	-0.0016	0.23	86	109
Chestnut-rumped Thornbill †	1.14	2.6	0.0146	2.28	55	47
Buff-rumped Thornbill	2.17	2.31	0.0014	1.06	44	48
Yellow-rumped Thornbill	6	5.95	-0.0006	0.99	28	32
Weebill	3.45	8.59	0.0514	2.49	37	24
Southern Whiteface	0.14	0	-0.0014	0	94	131
White-naped Honeyeater †	0.07	0	-0.0007	0	108	131
Black-chinned Honeyeater *	0.07	0.05	-0.0002	0.68	108	109
Brown-headed Honeyeater	0.1	0.09	-0.0001	0.91	100	102
Striped Honeyeater	3.1	1.98	-0.0112	0.64	40	51
Black Honeyeater †	0	0.05	0.0005		146	109
Brown Honeyeater †	0.03	0.05	0.0001	1.37	123	109

Common name	Drought rate (%)	Post-drought rate (%)	Δ Rates	Ratio	Drought rank	Post-drought rank
Painted Honeyeater *	2.28	3.35	0.0107	1.47	42	39
Singing Honeyeater †	0.66	1.04	0.0038	1.58	66	58
Fuscous Honeyeater †	0.03	0	-0.0003	0	123	131
White-eared Honeyeater	0.07	0	-0.0007	0	108	131
White-plumed Honeyeater	10.8	10.9	0.001	1.01	18	17
Noisy Miner	63.16	58.75	-0.0441	0.93	2	1
Yellow-throated Miner †	6.07	6.04	-0.0003	0.99	26	31
Red Wattlebird †	0.07	0	-0.0007	0	108	131
Spiny-cheeked Honeyeater	4.31	4.77	0.0045	1.11	31	36
Blue-faced Honeyeater	3.62	5.95	0.0232	1.64	35	32
Noisy Friarbird	0.31	0.14	-0.0017	0.46	77	93
Little Friarbird	3.41	6.23	0.0281	1.82	38	29
Jacky Winter	1.72	0.42	-0.013	0.25	49	76
Red-capped Robin	2.55	2.83	0.0028	1.11	41	45
Hooded Robin *	0.24	0	-0.0024	0	80	131
Eastern Yellow Robin	2.24	2.64	0.004	1.18	43	46
Grey-crowned Babbler *	25.32	28.17	0.0285	1.11	9	6
White-browed Babbler	0.1	0	-0.001	0	100	131
Varied Sittella *	0.52	0.19	-0.0033	0.36	70	88
Crested Shrike-tit	0.03	0.05	0.0001	1.37	123	109
Crested Bellbird †	0.03	0	-0.0003	0	123	131
Rufous Whistler	6.69	10.29	0.036	1.54	23	19
Grey Shrike-thrush	3.21	6.89	0.0368	2.15	39	26
Leaden Flycatcher †	0.07	0	-0.0007	0	108	131
Satin Flycatcher †	0	0.05	0.0005		146	109
Restless Flycatcher	1	0.94	-0.0006	0.94	58	60
Willie Wagtail	13.66	14.35	0.0069	1.05	16	13
Grey Fantail	0.79	2.12	0.0133	2.68	63	50
Spangled Drongo †	0.03	0	-0.0003	0	123	131
Magpie-lark	35.74	34.59	-0.0114	0.97	5	4
Ground Cuckoo-shrike	0.07	0.14	0.0007	2.05	108	93
Black-faced Cuckoo-shrike	7.97	8.97	0.01	1.13	21	23
White-bellied Cuckoo-shrike	0	0.05	0.0005		146	109
White-winged Triller	0.97	0.61	-0.0035	0.64	59	67
Olive-backed Oriole	0.03	0.05	0.0001	1.37	123	109
White-breasted Woodswallow	0.24	0	-0.0024	0	80	131
Masked Woodswallow	0.07	0.66	0.0059	9.58	108	65
White-browed Woodswallow	0.83	0.94	0.0012	1.14	62	60
Black-faced Woodswallow	0.1	0.05	-0.0006	0.46	100	109
Dusky Woodswallow	0.24	0.05	-0.0019	0.2	80	109
Little Woodswallow †	0.03	0	-0.0003	0	123	131
Pied Butcherbird	24.04	20.15	-0.0389	0.84	10	9
Grey Butcherbird	17.97	13.78	-0.0419	0.77	14	15
Australian Magpie	48.57	46.91	-0.0166	0.97	3	3
Pied Currawong †	0.76	0.8	0.0004	1.06	64	63

Common name	Drought rate (%)	Post-drought rate (%)	Δ Rates	Ratio	Drought rank	Post-drought rank
Australian Raven	28.7	9.72	-0.1898	0.34	7	22
Little Raven	1.03	1.27	0.0024	1.23	57	55
Little Crow †	0.97	1.42	0.0045	1.47	59	54
Apostlebird	35.36	34.07	-0.0128	0.96	6	5
White-winged Chough	15.42	17.32	0.019	1.12	15	11
Spotted Bowerbird †	0	0.05	0.0005		146	109
Richard's Pipit	0.14	0.19	0.0005	1.37	94	88
Singing Bushlark	0.07	0.14	0.0007	2.05	108	93
Skylark †	0.03	0.05	0.0001	1.37	123	109
Diamond Firetail *	0.14	0.19	0.0005	1.37	94	88
Zebra Finch	0.45	0.52	0.0007	1.16	72	71
Double-barred Finch	0.17	1.18	0.0101	6.84	89	56
Red-browed Finch †	0	0.05	0.0005		146	109
Mistletoebird	3.66	5.71	0.0205	1.56	34	35
Welcome Swallow	0.86	0.85	-0.0001	0.99	61	62
White-backed Swallow	0.07	0.05	-0.0002	0.68	108	109
Tree Martin	0.41	0.28	-0.0013	0.68	73	79
Fairy Martin	1.17	0.57	-0.0061	0.48	53	68
Clamorous Reed-Warbler	0.07	0	-0.0007	0	108	131
Brown Songlark	2.14	2.88	0.0074	1.35	45	44
Rufous Songlark	3.48	10.38	0.069	2.98	36	18
Silvereye	0	0.05	0.0005		146	109
Common Starling	12.18	9.96	-0.0222	0.82	17	20

2 – 6%; the Painted Honeyeater with a slight increase in reporting rate post-drought and the Brown Treecreeper and Superb Parrot with decreased reporting rates post-drought. The other 13 listed species were recorded in fewer than one percent of the surveys, with four being at the edges of their ranges.

Feeding guilds and taxonomic groups

Both mistletoe specialists, the Mistletoe Bird and Painted Honeyeater, were recorded about 1.5 times more frequently post-drought. Conversely, most honeyeaters showed declines or small increases. The exceptions were two of the larger species (Blue-faced Honeyeater and Little Friarbird), which had increases greater than 1.5 times for their reporting rates, in contrast to the similar sized Noisy Miner, which decreased, but was the most frequently recorded bird post-drought.

Foliage gleaning birds such as the Striated Pardalote, Western Gerygone, Weebill, and to a lesser extent Yellow Thornbill, had marked increases in their reporting rates, while other members of the Pardalotidae showed only small differences. Similarly, among the flycatchers, robins, and whistlers only the Grey Fantail, Rufous Whistler, and Grey Shrike-thrush increased post-drought, with other species showing little change. All fairy-wren species showed an increase, but only for the most common species (Superb Fairy-wren) was the increase large. The granivorous finches showed the same pattern.

The parrots declined, with the exception of the Eastern Rosella, which showed little change, and the Little Corella and Sulphur-crested Cockatoo which frequent riparian areas and had moderate to large increases. For parrot species with more than 1 % reporting rate during the drought, the largest declines were for the Cockatiel, the Superb Parrot, and Mallee Ringneck (Table 1).

Ten of the 14 species of diurnal birds of prey were recorded less often post-drought, but reporting rates were below 2 % for all species both during and after the drought (Table 1). Of the six species of cuckoos recorded post-drought all but one had increased in reporting rate, but reporting rates for all species were still below 1% post-drought.

Discussion

All but one of the commonest species from the drought period were rarer post-drought, and these covered a wide range of life histories and taxonomies, but were all larger species. There was relatively little evidence of similarity of response among congeneric species or within guilds or functional groups in our study area. The Fairy-wrens were the only taxonomic group that showed similar increases in reporting rates for all the species in the study area. This lack of consistency has been found for bird populations in other regions (Barrett *et al.* 2002; Mac Nally *et al.* 2009; Lindemayer and Cunningham 2011).

Australian inland birds and small mammals are capable

Table 2. Breakdown of the number of surveys (n) and of the number of species recorded per survey for each of the seven survey periods.

		Number of species per survey				
Period (year)	n	Minimum	Lower Quartile	Median	Upper Quartile	Maximum
2005/06	335	1	5	7	10	21
2006/07	1012	0	5	6	9	24
2007/08	853	1	5	7	9	18
2008/09	699	1	5	6	8	22
2010/11	855	1	4	6	8	21
2011/12	838	1	5	6	9	20
2012/13	426	1	5	7	9	17

of responding rapidly and dramatically to major rainfall events (Keast and Marshall 1954; Dickman *et al.* 1999; Burbidge and Fuller 2007). However, landbird species on the plains of central-western NSW showed limited and uneven responses to the drought-breaking rains and floods of 2010. Populations showed no rapid recruitment or recovery as might be expected based on some studies (e.g. Keast and Marshall 1954; Smith 1982; George *et al.* 1992), but increased slowly over the post-drought years.

Our surveys commenced four years into the declared drought, yet the mean number of species detected per survey by three years post-drought had just recovered to the level of the beginning of our drought period surveys indicating a broad suppression of bird populations that were slow to recover. The lowest mean number of species detected per survey occurred in the first post-drought survey period before much response to the rainfall, which fell after the 2010 spring breeding season.

Changes in reporting rates

We found a similar percentage of decliners, but fewer increasers and more species with no change than found for the regions encompassing our study area in Barrett and Silcocks (2002: NSW Southwestern Slopes and Darling Riverine Plains). There was no evidence in our data of the post-drought environment favouring either increasing or declining species identified by Barrett *et al.* (2007), and species constituting the declining, increasing, and no change groups were not identical for Barrett *et al.* (2007) and our study. This may in part reflect the continual flux in species abundances over time. It may also be driven by our focus on the agricultural lands at the eastern end of the Darling Riverine Plains bioregion, which also extends west into rangelands where cropping is less intense (Bedward *et al.* 2007) and hence different population dynamics could be expected. The surveys for both Atlases were in periods of greater cumulative rainfall than our study (Fig. 4), which may explain the smaller number of increasing species in our study.

Decreasers

Thirteen of the 15 most frequently reported birds of the drought period were encountered less frequently in the post-drought period. Seven of the sixteen species that declined in reporting rate by more than 20% were from that group and six were parrots. All of these species have

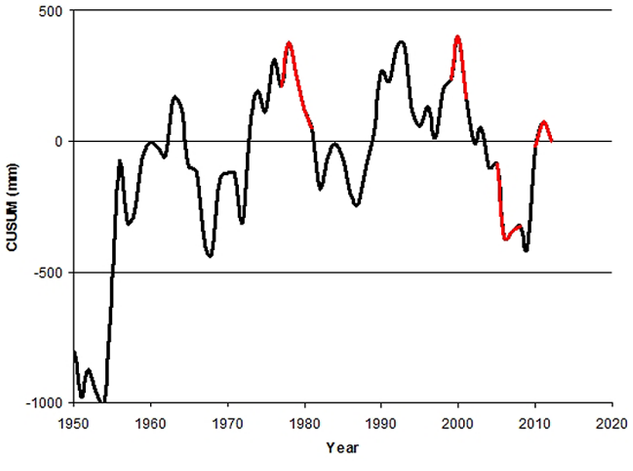

Figure 4. The cumulative summation of deviations from the mean (CUSUM) of rainfall for Trangie in the north-west of the study area (Bureau of Meteorology station 51049) calculated from rainfall records from 1923 to 2012. Periods highlighted in red on the graph show RAOU/Birds Australia bird surveys from January 1977 to December 1981, and from August 1998 to December 2001, and our drought and post-drought surveys.

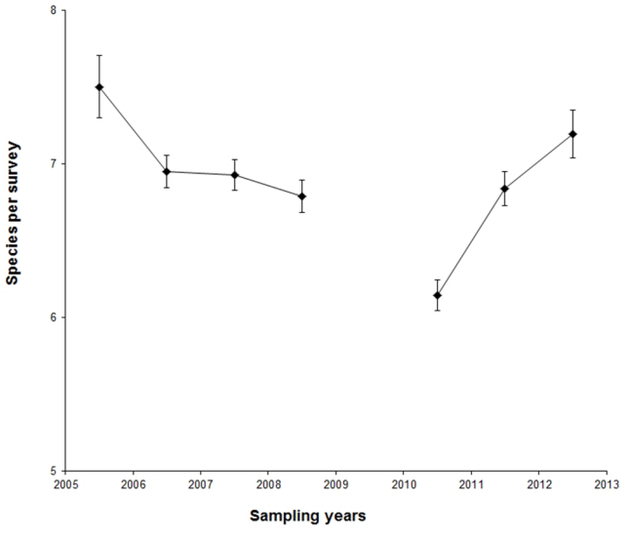

Figure 5. Mean number of species detected per survey (± 95% confidence limits) showing a decline across the drought period followed by an increase.

increased in the study area over the 25 years since the first Atlas (Ellis and Taylor 2013) and had relatively high reporting rates. Apart from the Superb Parrot, declines of these species are unlikely to be a cause for concern while they remain widespread in highly disturbed landscapes (e.g., Galah, Grey Butcherbird, Crested Pigeon). However, longer monitoring is required to see if these declines are a short-term response due to the preceding drought conditions or if their reporting rates have been depressed for the long-term by the type of environmental deterioration described by Mac Nally *et al.* (2009).

In contrast, the decline of the Jacky Winter, Brown Tree Creeper, Striped Honeyeater, and Superb Parrot are of immediate concern, as all are typical of woodland and well within their distributional or migrational ranges (Blakers *et al.* 1984) and had post-drought reporting rates below 5%. Two species are currently listed as threatened (Brown Tree Creeper, Superb Parrot) and all but the Superb Parrot have declined in our study area since the late 1970s (Ellis and Taylor 2013) and in some other parts of their range (Barrett *et al.* 2007 but see Lindenmayer and Cunningham 2011). Drought may have compounded the decline of these species, but seems unlikely to be the main driver for the continued low reporting rates. In less fragmented semi-arid landscapes, recovery of bird populations has been seen following drought (Smith *et al.* 1982). Continued decline post-drought when environmental conditions should be favourable may indicate populations that have reached critically low levels (Ford *et al.* 2009) or that the habitat degradation process described by Mac Nally *et al.* (2009) is happening in the woodlands of our study area.

Stable species

Species with little change (< 20% change) in reporting rate were a mix of taxonomic groups, food preferences and sizes. It included a group of larger species favoured by highly cleared environments e.g., Noisy Miner, Australian Magpie, Apostlebird, Eastern Rosella, that have shown a long-term increase in abundance in the study area (Ellis and Taylor 2013), all of which had high reporting rates (>10%). Also in this group was the Grey-crowned Babbler, a threatened species which would appear to currently have a stable population in this part of central-western NSW.

More notable are those species with little change in reporting rate and low post-drought reporting rates (<2%), but which are species that are typical of woodland and within their distributional range; Red-capped Robin, Eastern Yellow Robin, Peaceful Dove, and Restless Flycatcher. Populations of these species appear to have declined from historical sizes (Ellis and Taylor 2013) and the potential to increase during improved environmental conditions may be compromised by the patchiness of the woodland landscape (Zanette *et al.* 2000), by a general decline in woodland vigour (Mac Nally *et al.* 2009), or by the population density falling below a critical threshold (the Allee effect, Stephens *et al.* 1999).

Increasers

There is some evidence that increased rainfall in woodlands generates higher bird species diversity and abundance (Barrett *et al.* 2007). Some species show rapid increases in local abundance, either by breeding or migration, in response to changing environmental conditions that provide new food resources (Wyndham 1983; Zann *et al.* 1995). Such species might have been expected to respond to the flush of growth in our study area that appeared in 2010 and was maintained in many parts of the study area into 2012.

Some of the increaser species (e.g., Grey Shrike Thrush, Grey Fantail, Singing Honeyeater) appear to have had a long-term decline in our study area (Ellis and Taylor 2013). These species were a mix of feeding types and body sizes, but may have increased in response to increased food resources.

The increase in the two mistletoe specialists (Painted Honeyeater and Mistletoebird) may indicate that their food resource responded rapidly to the rain events. Both species are nomadic, moving in response to availability of mistletoe fruit. However, two other species that frequently feed on mistletoe fruit or flowers showed little change (Spiny-cheeked Honeyeater) or a decrease (Superb Parrot) in reporting rate. The Painted Honeyeater and Superb Parrot are migratory/nomadic species but only the former breeds in our study area and the increased reporting rate may also reflect improved breeding as well as food availability.

Grass growth was prolific in the study area in 2010-2011 (Fig. 3) and may explain the increase in reporting rate of the ground feeding and nesting Stubble Quail (and to a lesser extent Brown Quail and Little Button-quail). However, the Painted Button-quail was not detected post-drought. Finches might have been expected to increase dramatically given that they are known to have a strong breeding response to such conditions (e.g., Zebra Finch, Zann *et al.* 1995), but this was only evident for the Double-barred Finch.

Although five of the six species of cuckoos were observed more frequently in the post-drought period, reporting rates were all below 0.4% indicating low population levels in our study area making them hard to detect. The slow increase in populations of bird species for them to parasitise could indicate that breeding opportunities for this group may be limited in our study area.

Several species that increased post-drought were much rarer in our study area during the drought than during the first Bird Atlas surveys 25 years prior, for example, Double-barred Finch, Stubble Quail, and Grey Fantail (Ellis and Taylor 2013). At least two of these species were identified by Barrett *et al.* (2007) as undergoing widespread decline in woodlands (Double-barred Finch, Stubble Quail). However, the reporting rate for this finch in our study was below that calculated by Barrett and Silcocks (2002) for the Darling Riverine Plains bioregion for the first Bird Atlas, but the post-drought response may indicate potential for recovery of populations with appropriate management.

Thus only a subset of species from taxonomic groups or feeding guilds that might be expected to respond to the drought has done so. This might reflect that only some

species had sufficient population size in the vicinity to enable them to respond, either by breeding or immigrating from neighbouring areas.

Rare species

There was a high diversity of species present in our study area, but almost two thirds of the species had low reporting rates (< 1%) indicating sparse populations. Such sparse populations must be susceptible to stochastic catastrophes eliminating them from the landscape (Thomas 1990) or density impacts on their breeding success (Allee effect, Stephens *et al.* 1999). Indeed, birds such as the Hooded Robin, Southern Whiteface, White-eared Honeyeater, and Crested Bellbird which frequent inland woodlands were not recorded during our post-drought surveys and may be becoming locally extinct. Hooded Robin and Southern Whiteface are sedentary species that are within their distributional range in our study area and would be expected to be part of the avifauna of the area based on past records (Blakers *et al.* 1984; Higgins and Peter 2002).

For some species there are other potential explanations for low reporting rates. Species at the boundaries of their distributional ranges may be naturally at low abundance and fluctuate in response to changes in the core of the species' range (Opdam and Wascher 2004). Most of the edge species were at low abundance during the drought and remained so post-drought. Some species at the edge of their range are known to be nomadic in response to food resources (e.g., Budgerigar) or show seasonal movements (e.g., Silvereye) so that they are generally only in our study area outside the spring/summer period of our surveys.

Conclusion

The ecological drivers of which species increased post-drought and those that did not are unclear. The significant rainfall events of 2010 have returned little vigour to the woodland avifauna in the small remnants of the central wheatbelt of NSW but these remnants still contain a wide diversity of species. These remnants cover a small percentage of the landscape and they did not seem to generate "boom" populations of any species other than Stubble Quail when the drought broke, so many species remain rare in this landscape. This supports the conclusions of Mac Nally *et al.* (2009) that there is depressed vigour in woodlands of south-eastern Australia and that we need to actively restore parts of this landscape if large viable populations of some native woodland fauna are to be maintained.

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